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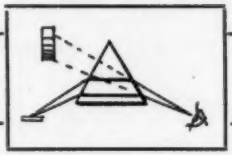

SEPTEMBER
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THE SENSITIZATION OF ORDINARY PHOTOGRAPHIC PLATES TO WAVE LENGTHS BELOW 2500A

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[Cancer Research Laboratories, University of Pennsylvania. Graduate School of Medicine. Received June 18, 1932]

Introduction

Persons interested in photographically detecting radiations in the region below 2500A are confronted with the problem of the diminishing sensitivity of the ordinary photographic plate. Schumann plates are now most generally used for this purpose and indeed have been invaluable in exploring the far ultraviolet region of the spectrum as well as for certain other fields of scientific research. The Schumann plates, however, have certain disadvantages: the sensitive coating is so fragile that the slightest brush will sometimes render a plate valueless; they are grainy; they are not readily obtainable and their cost is relatively high.

Ordinary plates covered with a selected,[1,2,3] thin, uniform coat of fluorescent mineral oil are quite satisfactory for certain purposes. On

[1] J. Duclaux and P. Jeantet, *Plaques Photographique pour l'Ultraviolet Extreme*, J. de Physilque et le Radium, *2*, p. 156; 1921.

[2] G. R. Harrison, *Photographic Sensitometry with Fluorescent Oils*, J.O.S A., *11*, p. 113; 1925. Certain samples of Nujol Mineral Oil are poor sensitizers.

[3] C. E. K. Mees, *The Color Sensitivity of Photographic Materials*, J. Franklin Inst. p. 525, May, 1926.

account of the vapor pressure of certain constituents of the fluorescent oil it is not readily adaptable to high-vacuum work.

The Eastman Kodak Company has recently put on the market an ultraviolet sensitizing solution which should be of great aid in certain scientific investigations.[4]

Ordinary photographic plates are most sensitive to radiations between the wave lengths 2500A and 5000A. The diminishing sensitivity at the lower wave length is due, not to the silver halides, but to the absorption of the energy by the gelatin which supports the sensitive crystals. The absorption of the gelatin begins at 2500A; consequently the

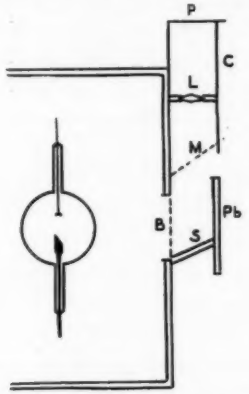

FIG. 1. *Diagram of apparatus for the detection of fluorescence under x-ray excitation.*

sensitive range can be increased by applying a thin coat of fluorescent material which would efficiently convert the shorter waves into the wave length range to which the plate is most sensitive.

There are many other requisites of a good sensitizer and they may be briefly summarized as follows: (1) One must be able to apply it conveniently in a thin, uniform layer; (2) The graininess of the layer should not be greater than that of the plate; (3) It should not affect the emulsion of the plate or diminish its sensitivity; (4) The coat should be durable; (5) It must not interfere with the proper development of the plate; (6) For high vacuum work it must have a low vapor pressure; (7) For quantitative work it is desirable to have it of such a nature as to preserve the laws of photographic blackening, or if possible, have the blackening conform to a more simple law.

[4] C. E. K. Mees, *Photographic Plates for use in Spectroscopy and Astronomy.* J.O.S.A., *21*, p. 753; 1931.

The present paper deals with a group of ultraviolet sensitizers which were found in the course of an investigation on the fluorescence of a large number of organic and inorganic compounds produced by x-ray excitation. During this work it was found, as was to have been expected,[5,6] that for many compounds the quality of the fluorescent light, if any occurred, was independent of the exciting radiation. Consequently a number of substances which emitted fluorescent bands in the region of 2500 to 5000A were tested for their sensitizing properties.

Fig. 1 is a diagram showing the method used in detecting the fluorescent light produced by x-ray excitation. The samples were put into a twenty-four compartment wooden block and placed at *S*. Visual obser-

TABLE 1.

Chemical formula	Trade name	Solvent	Concentration approx.	Remarks
1. 1 naphthylamine, 4 sulfonic acid	Naphthionic Acid	Water	2%	Add 4% Na_2O_2 (approx.)
2. 2 naphthylamine, 1 sulfonic acid	Eastman's T 386	"	2%	" 4% " "
3. 2 naphthylamine, 6 sulfonic acid	Brönners acid	"	2% = Saturated solution	" 4% " "
4. 2 naphthylamine, 6–8 disulfonic acid	Amino *G* acid	"	4%	" 4% " "
5. 2 naphthol, 6–8 disulfonic acid	*G* acid	"	4%	" 4% " "
6. Alpha naphthylamine		Ethyl acetate	2%	Add 4 cc alcoholic solution of white shellac to 100 cc sensitizing solution
7. Fluorene		"	2½%	" " " "
8. Carbazole		"	2%	" " " "
9. Ethyl carbazole		"	2%	" " " "

vations were made by inserting a mirror at *M*, thus protecting the observer from any direct or scattered x-rays. The mirror being removed, the ultraviolet light was detected by the camera *C* having a quartz lens *L* and an ultraviolet sensitized plate *P*. Because a quartz lens is not achromatic the camera would be most sensitive to those wave lengths which are in best focus, hence this method is not uniformly sensitive throughout the whole light region. Considerable precaution was taken by using adequate lead shielding to prevent direct or scattered x-rays from striking the photographic plate or the observer. *B* was a blackened card board which allowed x-rays but not visible light from the filament or anticathode to fall on the samples at *S*. By comparing visual observations with those recorded on the photographic plate a rough determina-

[5] Lenard, Schmidt, Tomaschek. Handbuch der Experimental Physik, von Wien and Harms, *23*, no. 2, chapter 13.

[6] E. L. Nichols and F. G. Wick, *The Relation between Certain Types of Luminescence.* J.O.S. A., *22*, p. 357; 1932.

tion of the amount of ultraviolet fluorescent light was made. To ascertain more exactly the quality of the fluorescent light a spectrogram was taken. This was done by allowing a beam of x-rays to fall on a sample placed just in front of the slit of a quartz spectrograph.

Table 1 is a compilation showing some of the substances which can be used as sensitizers. Practically all the sodium salts of naphthol or naphthylamine sulfonic acids containing an excess of sodium carbonate are good sensitizers, providing their fluorescent light is in the sensitive range of the photographic plate used. For instance, since a part of the fluorescent light of *G* salt is in the green part of the spectrum, it is relatively ineffective as a sensitizer.

METHOD OF SENSITIZING THE PLATES

The procedure for sensitizing with any of the water soluble substances such as amino *G* salt and Brönner's acid, is quite simple. After preparing the solutions as indicated in Table 1, they should be cooled to at least 18°C and filtered.

Plates of desired grain or sensitivity are then submersed in the solution for a few seconds, the entire surface being lightly rubbed with a piece of absorbent cotton to insure a uniform coat. They are then removed and allowed to dry in a vertical position on an ordinary plate drying rack. This results in a rather durable coat of microcrystals which provides an excellent sensitization for work where resolution of detail is important. After exposure, and just before developing and fixing in the usual manner the plates are dipped into a pan of water or rinsed under the water tap for an instant to insure uniform development. Plates sensitized in this manner fulfil the requirements for good sensitization as outlined in the first part of this paper.

The water insoluble substances may be used by depositing them on the plate from a suitable organic solvent but it is then more difficult to obtain a suitable coat. There is a tendency for large crystals to form. To prevent this and also to enable spreading a more uniform and durable layer, a substance such as shellac, or collodion, must be added. The entire surface is quickly rubbed with a bit of absorbent cotton which has been dipped into the sensitizing solution and rapidly dried by gently blowing over it. To insure uniform development the plates should be thoroughly washed in acetone, then immediately placed in water before developing in the usual manner. This is also a good procedure to follow when using fluorescent oil and Eastman sensitizers. Plates sensitized in this manner, as may be observed from Figs. 2, 3, 4, 5 and 6 are slightly

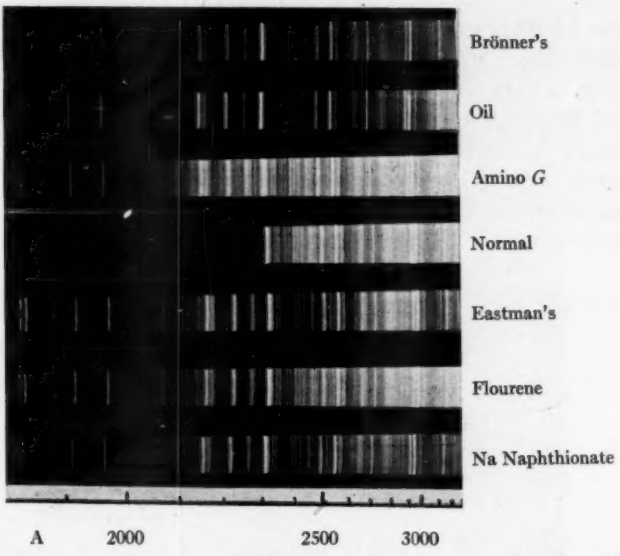

FIG. 2. *Spectrograms of the aluminum spark showing the increased sensitivity of sensitized Eastman 40 plates as compared with normal (unsensitized) plates. The wave length of the line at the extreme left is 1854A.*

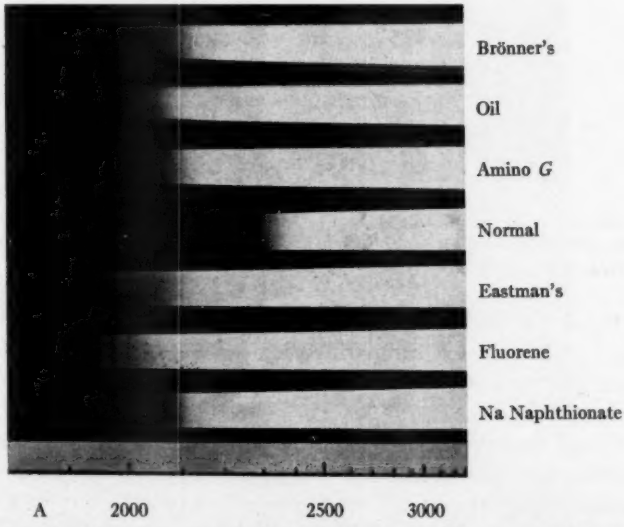

FIG. 3. *Spectrograms of the hydrogen arc showing the increased sensitivity of sensitized Eastman 40 plates as compared with normal (unsensitized) plates.*

more sensitive than those treated with the water soluble sensitizers but owing to their graininess do not give as good resolution of detail.

Fig. 2 shows spectrograms of the aluminum spark taken with an E 31 Hilger quartz spectrograph. The spectrograms show the increased sensitivity of Eastman 40 plates when various sensitizers are used. A normal, i.e., unsensitized, plate is inserted for comparison. Fig. 3 is similar to Fig. 2 except that a hydrogen arc was used as a source of ultraviolet light.

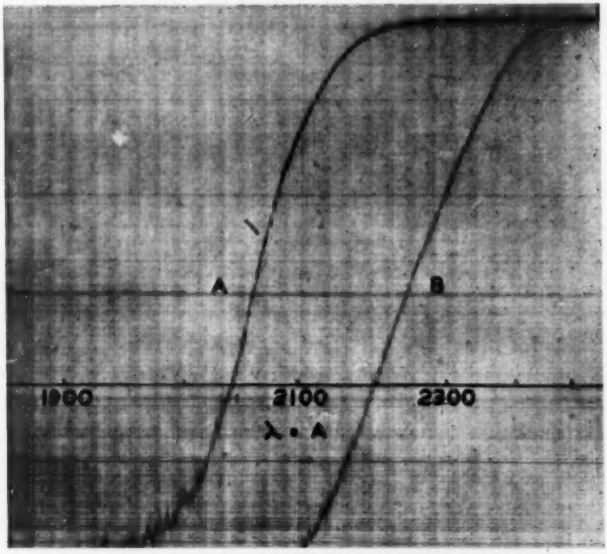

FIG. 4. *Densitometer tracings of spectrograms of the hydrogen arc showing the increased sensitivity of amino G sensitized plates (curve A) as compared with unsensitized plates (curve B). The ordinates represent the degree of blackening in arbitrary units.*

Fig. 4 is a densitometer tracing made with a Kraus, Hamburg, Germany, densitometer, comparing the degree of blackness of the unsensitized Eastman 40 plate (curve *B*) and a similar plate sensitized with amino *G* sensitizer (curve *A*). The amino *G* curve is typical of the naphthol and naphthylamine sulfonic acids. Brönner's acid is every bit as good as the amino *G* acid. Fig. 5 is a similar tracing except that the comparison is between a plate sensitized with fluorene (curve *E*) and a normal plate (curve *F*). Fig. 6 is a similar comparison of a plate sensitized with Eastman's ultraviolet sensitizer and one sensitized with a selected

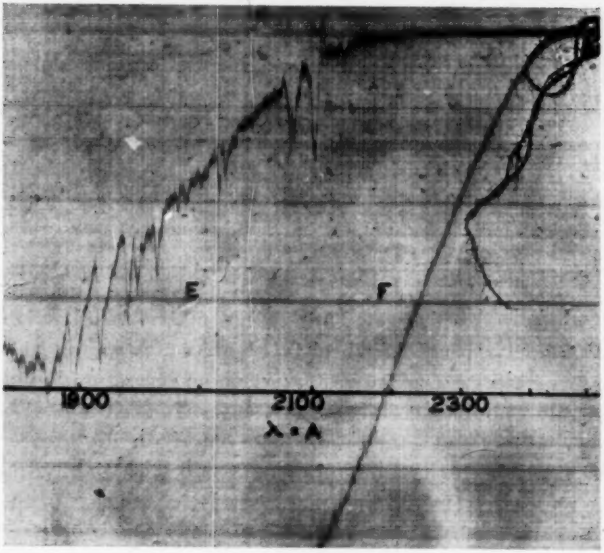

FIG. 5. *Densitometer tracings of spectrograms of the hydrogen arc showing the increased sensitivity of a plate sensitized with fluorene (curve E) as compared with an unsensitized plate (curve F). The ordinates represent the degree of blackening in arbitrary units.*

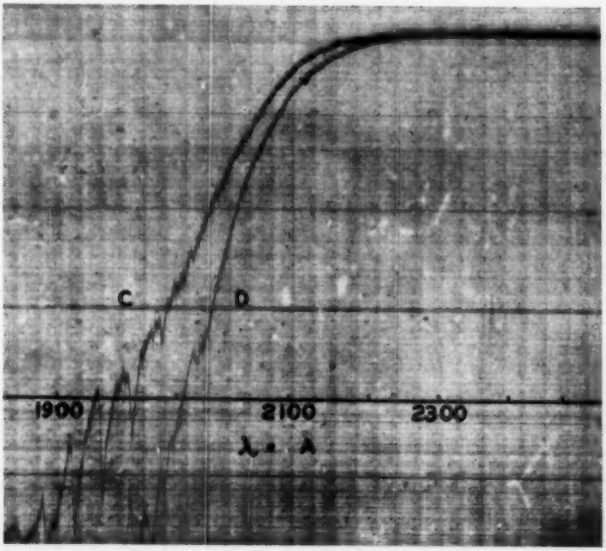

FIG. 6. *Densitometer tracings of spectrograms of the hydrogen arc comparing the sensitivity of an oil sensitized plate (curve D) and a plate sensitized with Eastman ultraviolet sensitizing solution (curve C). The ordinates represent the degree of blackening in arbitrary units.*

fluorescent mineral oil. Carbazole, ethyl carbazole and alpha naphthylamine are slightly less efficient as sensitizers than fluorene.

Since the spectrograms represented in Figs. 4, 5, and 6 all received the same amount of radiation, the curves are comparable. The diminishing blackness at the short wave length end is probably not due to a diminishing sensitivity of the sensitized plates but to the diminished amount of radiation which reaches the plate.

SUMMARY

The characteristics of and procedures for using a number of substances which will sensitize photographic plates to ultraviolet light below 2500A have been described. Some are water soluble and of fine grain and therefore are adapted to work requiring resolution of detail. Some are soluble only in certain organic solvents. Their crystals are usually somewhat larger and their sensitizing power slightly greater. Spectrograms taken with the aluminum spark and with the hydrogen arc show the increased sensitivity of plates sensitized with six of these substances as compared with an unsensitized plate. Densitometer curves, taken with a Kraus densitometer, also show these results in another form.

We are greatly indebted to Professor W. F. G. Swann for allowing us to carry on a part of this work at the Bartol Research Foundation, Swarthmore, Pennsylvania.

LIMITATIONS OF A BLANKET CALIBRATION CHART FOR READING DISPERSIONS ON THE ABBE REFRACTOMETER

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Received June 27, 1932]

ABSTRACT

The usefulness of the Abbe refractometer equipped with compensating prisms can be limited seriously, for measurement of dispersions, by too liberal application of a blanket calibration chart to many individual instruments. Such a chart has been checked by calculation directly from the Abbe question for the dispersion. Incidentally, this basic formula is given in detail, in the algebraically exact and the approximate form, and also its derivation, which is not widely available. In addition, the expression was derived entirely in terms of the *D*-index of the test substance as the single independeng variable, which it is ultimately, a form not appearing in Abbe's treatise.

Introduction

The refractometer equipped with compensating prisms according to Abbe has many advantages. A monochromatic index can be measured with ordinary white light. At the same time an approximate value of the dispersion, $n_F - n_D$, is obtainable from the reading on the drum of the compensating prisms after the critical border in the field of view has been achromatized. For both these reasons and because of large range of index-measurement and small amount of test substance required, this type of instrument is widely applicable in industrial and scientific laboratories.

Its precision in refractive index for a single wave length (*D*), is usually stated to be a few units in the 4th decimal place. The feeling of the writer, after many careful measurements on this instrument, is that with attainable precision of technique one can have confidence in the index so determined, to within 2 units in the 4th decimal place. Apparently, corresponding precision in the dispersion determined by achromatization with the compensating prisms has not usually been insisted upon. Here again the writer is of the opinion that much greater precision in this respect than is generally expected, might be made available.

Object

Two possible reasons for discrepancies from correct values of dispersions measured by this method may be offered: (1) limited precision of manufacture; (2) limited applicability to the particular instrument, of

the blanket calibration chart accompanying it. With a particular refractometer mentioned in a previous paper[1] (instrument *A*), the second limitation was found to be the chief source of error.

In order to indicate the extent to which these two factors were responsible in this case for lowered precision in measurement of the dispersion, some numerical data will be given. A working formula is printed in condensed form on the chart. Since this is the same algebraically as that of the equation for the dispersion developed in Abbe's original treatise,[2] it may be regarded as the same equation, rather than one of empirical character having the same general form. On this basis numerical values from the calibration chart may be compared with corresponding values calculated from the Abbe equation. Before this is done

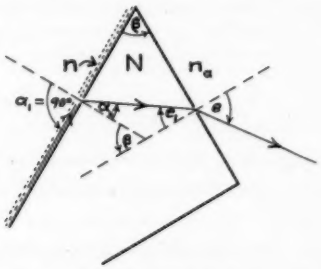

FIG. 1. *Optical scheme of Abbe prism.*

however, it should be worthwhile and of interest to the readers of this journal, to give the derivation, briefly, of this equation. Abbe's treatise of 1874, containing his derivation, has been long out of print. No English translation has been made as far as the writer is aware, and the derivation appears not to be readily available elsewhere.

EXACT DERIVATION OF THE ABBE EQUATION IN THE DIFFERENTIAL FORM

In his analysis Abbe used indices relative to air and neglected the dispersion of air. The derivation will be made here on an exact basis, followed by the approximation he gave as working formula. In Fig. 1, which is self-explanatory, the upper Abbe prism is shown in conventional orientation according to Southall. This is the inversion of the position in Abbe's diagram. Following Southall's convention of signs, and

[1] R.S.I., *2*, pp. 466–501; 1931.

[2] Neue Apparate zur Bestimmung des Brechungs- und Zerstreuungs-vermögens fester und flüssiger Körper. Jena, 1874.

comparing with his symbols, we here use (1) $e \equiv (\alpha_2')_k$, (2) $e_1 \equiv (\alpha_2)_k$, (3) $\alpha_k \equiv (\alpha_1')_k$, (4) β, (5) N, (6) n, where Abbe employed respectively (1) α, (2) β, (3) γ, (4) ω, (5) ν (relative), (6) n (relative).

The three basic equations for the critically emergent ray are:

$$\sin e = (N/n_a) \sin e_1, \tag{1}$$

$$\alpha_k = e_1 + \beta, \tag{2}$$

$$n = N \sin \alpha_k, \tag{3}$$

where the law of refraction appears in (1) and (3), and N, n_a, n are absolute indices of prism, air, and test substance. The procedure is by a series of differentiations and substitutions. Differentiating (2) and (3), $d\alpha_k = de_1 = \tan \alpha_k (dn/n - dN/N)$. Differentiating (1), $\cos e \, de = (N/n_a)(\cos e_1 \, de_1 - \sin e_1 \, dn_a/n_a + \sin e_1 \, dN/n_a)$, whence by substitution for de_1,

$$dn = (\sin \beta dN + N \sin e_1 \cos \alpha_k dn/n_a + n_a \cos e \cos \alpha_k de) \cos e_1. \tag{4}$$

In order to obtain (4) entirely in terms of index n of the test substance (a form which does not appear in Abbe's treatise) and of the differentials dN, dn_a, de and also of the constants β, N, n_a, substitutions for the angles e, e_1, α_k, will be made. From (3), $\cos \alpha_k = (N^2 - n^2)^{1/2}/N$; from (2), $\cos e_1 = \cos(\alpha_k - \beta) = (n \sin \beta + (N^2 - n^2)^{1/2} \cos \beta)/N$; from (1), $\sin e_1 = n_a \sin e/N$, which from Eq. (4) of the preceding article, *viz.*, $\sin e = (n \cos \beta - (N^2 - n^2)^{1/2} \sin \beta)/n_a$ (changing the sign of e to fit Fig. 1 here), becomes $\sin e_1 = (n \cos \beta - (N^2 - n^2)^{1/2} \sin \beta)/N$, so that

$$\cos e_1 = (N^2 - n_a^2 \sin^2 e)^{1/2}/N = [N^2 - (n \cos \beta - (N^2 - n^2)^{1/2} \sin \beta)^2]^{1/2}/N.$$

Also,

$$\cos e = (1 - \sin^2 e)^{1/2} = [n_a^2 - (n \cos \beta - (N^2 - n^2)^{1/2} \sin \beta)^2]^{1/2}/n_a.$$

The sign before every radical will always be positive. Substitution for α_k and e_1, but not for e, in Eq. (4) gives

$$dn = [N \sin \beta dN + (N^2 - n^2)^{1/2}(\sin e \, dn_a + n_a \cos e de)]/(N^2 - n_a^2 \sin^2 e)^2. \tag{4a}$$

Finally, substituting for e,

$$dn = \left[\frac{N \sin \beta dN + (N^2 - n^2)^{1/2}[(n \cos \beta - (N^2 - n^2)^{1/2} \sin \beta) dn_a/n_a + [n_a^2 - N^2 + (n \sin \beta + (N^2 - n^2)^{1/2} \cos \beta]^2]^{1/2}]}{n \sin \beta + (N^2 - n^2)^{1/2} \cos \beta} \right] \tag{5}$$

APPROXIMATE FORMS

Omitting the term in dn_a, which causes only very negligible error, and applying the differential form (5) to the wave length interval F to C, an expression results of the form

$$\Delta n = A + B'\Delta e. \tag{6}$$

As explained below, $\Delta e = 2k \cos \theta$, so that

$$\Delta n = A + B \cos \theta, \tag{7}$$

where $B = 2kB'$, and where, from (4),

$$A = \sin \beta \Delta N / \cos e_1; \; B = 2k \cos e \cos \alpha_k / \cos e_1, \tag{8}$$

expression given by Abbe. From (5),

$$A = N \sin \beta \Delta N / G; \; B = 2k\left[(N^2 - n^2)(1 - N^2 + G^2)\right]^{1/2}/G, \tag{9}$$

where $G = n \sin \beta + (N^2 - n^2)^{1/2} \cos \beta$. The dispersion and indices in (6), (7), (8), (9), are all relative to air, with no change in symbols. The equation in Abbe's form, (7), (8), requires calculation with the aid of (1), (2), (3). The angles e, e_1, α_k were for D-light, likewise, in expression (9), index n of the test substance. Angle e could be measured directly.

MEASUREMENT OF Δe

Measurement of Δe was accomplished by the pair of similar Amici direct-vision prisms (C-prisms) introduced by Abbe, capable of rotation oppositely at the same rate about a common axis. They produce a dispersion of the two limiting colors equal and opposite to Δe, thus *achromatizing* the critical border. If θ is the known angle through which each of these two prisms has been turned in opposite directions from the zero position, in order to achromatize for the two colors, and if k is the maximum angular dispersion due to one of the C-prisms alone, then $\Delta e = 2k \cos \theta$, where θ is known from the reading on the drum. In Eq. (6), Δe is to be expressed in radians.

This dispersion compensating Δe causes the critical edges for at least two colors (determined by the design) to coincide, very nearly at any rate, in the focal plane of the observing telescope. If only these two colors were present in the source of light it would be possible to bring about precise coincidence in this way. If the same compensation for the particular liquid is present with white light, the two particular critical edges coincide and the whole spectrum has contracted to the extent that achromatization is said to be present. Usually there will be a very

narrow secondary spectrum (an ordinary achromatic lens is a somewhat similar case). Abbe concluded that when an observer has achromatized the C-prisms with white light, such as daylight, in the source, the two colors of the C and the F Fraunhofer lines could usually be regarded as coincident. He therefore suggested these two colors for limiting the dispersion interval.[3]

TWO METHODS OF ASSEMBLY OF THE COMPENSATING PRISMS

There are two possible methods of assembly of the C-prisms with respect to the scale of the drum (cf. Fig. 6, previous paper, p. 474): (1) $Z=0$ at $\theta=0$ (or 360°), so that $\theta=3Z$; (2) $Z=0$ at $\theta=180°$, so that $\theta=180+3Z$, and $\cos\theta=-\cos(3Z)$. Here $Z=Z_a$, the achromatic reading on the drum with a given test substance (practically, the average of the drum readings at the two possible achromatic positions). The working formula on the chart had the form $\Delta n=A-BS$, with the provision that the sign of S is negative for $0<Z<30$, and positive for $30<Z<60$. For instrument A, $S=-\cos\theta=\cos(3Z)$.

APPLICABILITY OF CHART VALUES OF A and B

In the preceding article[1] it was noted (p. 494, r9) that the dispersions $(\Delta n)_A$ as found by achromatization with instrument A, and with values

TABLE 1. *Error in dispersions by achromatization, instrument A, using chart values of A and B*

Liq.	(1) $(n_D)_A$	(2) $(n_D)_B$	(3) Differences		(4) $(\Delta n)_A$	(5) $(\Delta n)_B$	(6) Differences	
			$\times10^4$	%	$\times10^5$	$\times10^5$	$\times10^5$	%
a	1.3303	1.3294	+9	+0.068	283	531	−248	−46.6
b	1.3599	1.3593	+6	+ .044	470	657	−187	−28.5
d	1.4609	1.4607	+2	+ .037	879	966	− 87	− 9.0
f	1.6275	1.6276	−1	− .006	3345	3531	−185	− 5.2

of A and B (corresponding to n_D read on this refractometer and checked with the known value for the test liquid), obtained from the chart supplied with the instrument, showed increasing percentage disagreement (r19) from check values with decreasing dispersions and indices.

[3] Although since Abbe's day the colors F, D, C, have played an extensive role in lens design and the description of optical glasses, it is of interest to note that for these purposes other colors have gained favor. For example, instead of the D-line, λ5609 (Pb) has been proposed and used in England because this line is located in the most sensitive region of the eye, while in Germany λ5461 (Hg) has its adherents. (See Trans. Opt. Soc., *32*, pp. 69–72; 1930–1).

Table 1 of the present paper gives (col. 1) for four different test liquids the values, $(n_D)_A$, of the D-index by achromatization with refractometer and also the check values (c2) from book (Landolt-Börnstein Tables, 1912, checked with Internat'l Crit. Tables, 7, 1930), and the differences (c3). The dispersions by achromatization (c4) compared with the check values (c5), show the marked differences (c6) mentioned. All values in this table are relative to air, although the dispersions remain practically the same whether absolute or not.

TABLE 2. *Calculation of A and B from Abbe's equation, and comparison of the corresponding chart values*

Liq.	(1) $(N^2-n^2)^{1/2}$	(2) G	(3) A $\times 10^2$	(4) A_c $\times 10^2$	(5) Differences $\times 10^4$	(5) Differences %	(6) B $\times 10^2$	(7) B_c $\times 10^2$	(8) Differences $\times 10^4$	(8) Differences %
a	1.19313	1.74186	2.8136	2.7003	−11.33	4.03	3.2933	3.6634	+37.01	11.25
b	1.15895	1.75135	2.7984	2.6853	−11.31	4.04	3.2436	3.5379	+29.43	9.08
d	1.02821	1.77637	2.7590	2.6478	−11.12	4.03	2.9766	3.0908	+11.42	3.83
f	0.73606	1.78012	2.7520	2.6433	−10.87	3.95	2.1401	2.1066	− 3.35	1.56

Values of A and B (Table 2, Columns 3, 6) were calculated from (9), with book values of n_D(1, 2), from which also the corresponding values, A_c, B_c, (1, 4, 7) were taken from the chart. (If values of n_D as read on the refractometer (1, 1) are used instead, the A's recalculated in this manner differ from the first amounts by -3, -2, -1, $+12$ units in the 6th decimal place respectively for the four liquids, and the B's by -15, -12, -7, $+15$ units in the 6th decimal place, while the dispersions found from these recalculated A's and B's are larger by $+0.7$, $+0.6$, $+0.3$, $+1.8$ units in the 5th decimal place. These differences are negligible.) The differences between the calculated and the chart values of A and B are noted (2, 5, 8).

Numerical constants of the refractometer (see previous paper, pp. 482, −5, −7) for the calculations were: $\beta = 60°54'$, $\sin\beta = 0.87377$, $\cos\beta = 0.48634$, $N_D = 1.7863$, $N_F = 1.8091$, $N_C = 1.7777$, so that $N \sin\beta$ $\Delta N = 0.049010$, while $2k = 180' = 0.05236$ radians.

As a check on the calculated values of A and B (2, −3, 6), expressions (9), the dispersions were calculated (3, −9) from (6), where B' (3, −7) $= B/(2k)$ and $1/(2k) = 1.9098$, and these were compared (3, −10) with book values (1, −5). In this calculation, to avoid the effect of any possible instrumental error entering through the factor $\cos\theta$, (7), determined by the reading on the achromatizing drum, the Abbe equation in form

TABLE 3. *Checking of calculated values of A and B through the dispersions; effect of calculated Δe and of drum reading*

Liq.	(1) n_F	(2) n_C	(3) e_D (°)	(3) e_D (′)	(4) $e_{F'}$ (°)	(4) $e_{F'}$ (′)	(5) e_C (°)	(5) e_C (′)	(6) Δe $\times 10^3$ rads.	(7) B'
a	1.3332	1.3279	−23	19.8	−24	50.6	−22	45.7	−3.6332	0.62897
b	1.3639	1.3574	−20	34.8	−22	2.0	−20	3.0	−3.4616	.61948
d	1.4675	1.4579	−10	50.2	−12	10.0	−10	21.4	−3.1591	.56849
f	1.6526	1.6173	+ 8	32.1	+ 9	14.5	+ 8	9.0	+1.9053	.40873

TABLE 3. (*Cont'd.*)

(8) $B'\Delta e$ $\times 10^3$	(9) Δn $\times 10^5$	(10) Diff. $\times 10^5$	(11) cos θ	(12) B cos θ	(13) Δn $\times 10^5$	(14) Diff. $\times 10^5$	(14) Diff. %
−2.2852	528.4	−3	−0.66327	−2.1843	629.3	+ 98	18.4
−2.1444	654.0	−3	− .62932	−2.0413	757.1	+100	15.2
−1.7959	963.1	−3	− .57501	−1.7116	1047.4	+ 81	8.4
+0.7787	3530.7	0	+ .32144	+0.6879	3439.9	− 91	2.6

(6) was applied, with values of Δe (3, −6) calculated from Eq. (4) of the preceding paper, changing the sign of e to fit Fig. 1 here, *viz.*, $\sin e = (n \cos \beta - (N^2 - n^2)^{1/2} \sin \beta)$, the indices being relative to air. These recalculated values of Δe are regarded as slightly more precise (1′ to 2′) than those previously reported (p. 491, col. 27).

INSTRUMENTAL ERROR

The drum readings, $(Z_a)_{av}$ (reference 1, p. 491, col. 29), were next used for $\cos \theta [= -\cos (3Z_a)]$. The product $B \cos \theta$ (2, −6; 3, −11) added to A (2, −3), Eq. (7), gave Δn (3, −13). This manner of calculation left much smaller discrepancies (3, −14) between the calculated and the comparison values of the dispersions, ranging from +18.4 percent for methyl alcohol to −2.6 percent for CS_2, than where the drum readings were used with values of A and B from the chart (1, −6).

This remaining error might be due either to an incorrect determination of $2k$, or to instrumental error affecting $\cos \theta$ through Z_a, the drum reading at achromatization. Assuming that all the remaining error (3, −14) is attributable to an incorrect value of $2k$, and calculating, from (7), $2k = (\Delta n - A)/(B' \cos \theta)$, using book values of Δn (1, −5), the calculated $A, -B'$, (2, −3; 3, −7), and the experimental $\cos \theta$ (3, −11), the resulting $2k$ was found (4, −3).

A weighted average of 190′ for these four values of $2k$, was tried for calculating new values of B, designated B_1 (4, –4), where $B_1 = [2k_2/(2k_1)]$ B, and $2k_1 = 180'$, $2k_2 = 190'$, so that $B_1 = 1.0555\ B$, where B is from 2, –6. The errors in Δn (4, –6), calculated from (7), with values of $\cos\theta$ (3, –11), are now all less than 5 percent, although showing a slight progressive change. Taking the average, 188.5′, of the first three values of $2k$ (4, –3), which show excellent agreement, and solving similarly for B, designated B_2 (4, –7), so that $B_2 = 1.0472\ B$, we obtain much diminished errors (4, –9), except a very small increase for CS_2.

TABLE 4. *$2k$ from Eq. (7), and calculation of corresponding dispersions; Z_a from Eq. (7), and comparison with experimental values*

Liq.	(1) $(\Delta n - A)$ $\times 10^2$	(2) $B' \cos\theta$	(3) $2k$ $\times 10^2$ (rads.)	(3) $2k$ (′)	(4) B_1 $\times 10^2$	(5) Δn $\times 10^5$	(6) Diff. $\times 10^5$	(6) Diff. %
a	−2.283	−0.41718	5.4724	188.1	3.4761	508	−23	4.3
b	−2.141	− .38985	5.4918	188.8	3.4236	644	−13	2.0
d	−1.793	− .32689	5.4850	188.6	3.1418	952	−14	1.4
f	+0.779	+ .13138	5.9294	203.8	2.2589	3478	−53	1.5

TABLE 4. (*Cont'd.*)

(7) B_2 $\times 10^2$	(8) Δn $\times 10^5$	(9) Diff. $\times 10^5$	(9) Diff. %	(10) Z_a	(11) $(Z_a)_{av}$	(12) Diff.	(13) ΔZ	(14) $\Delta(\Delta n)$ $\times 10^4$
3.4487	526	− 5	0.9	44.63	43.85	+0.78	0.3	3.9
3.3967	661	+ 4	.6	43.77	43.00	+ .77	.4	5.3
3.1171	966	0	0	42.35	41.70	+ .65	.4	5.1
2.2411	4372	−59	1.7	22.88	23.75	− .87	.5	5.3

Under the assumption now that 180′, as previously determined, is the correct value of $2k$, but that there is an error constant in character in the design or mounting of the C-prisms, then, since from Eq. (7) $\cos\theta = (\Delta n - A)/B = -\cos(3Z_a)$, we may solve for Z_a (4, –10) and compare with the average experimental reading (4, –11). Since the drum was read to 0.1 unit, it is seen (4, –12) that the differences are all well above this amount. In reading Z_a on the instrument it had been noted that corresponding readings in the right and the left positions did not agree perfectly. The difference, ΔZ (4, –13), in the two readings varied, depend-

ing on the test liquid, from 0.3 to 0.5 div., the positive readings being in all cases the larger. Corresponding differences in Δn, designated $\Delta(\Delta n)$ (4, –14), would amount to 4 or 5 units in the 4th decimal place. Since the two Z_a-readings were always averaged, the upper limit of any possible error in Δn due to this lack of symmetry surely cannot be greater than half this amount, to estimate, as one expects a cancelling effect in the two oppposite errors.

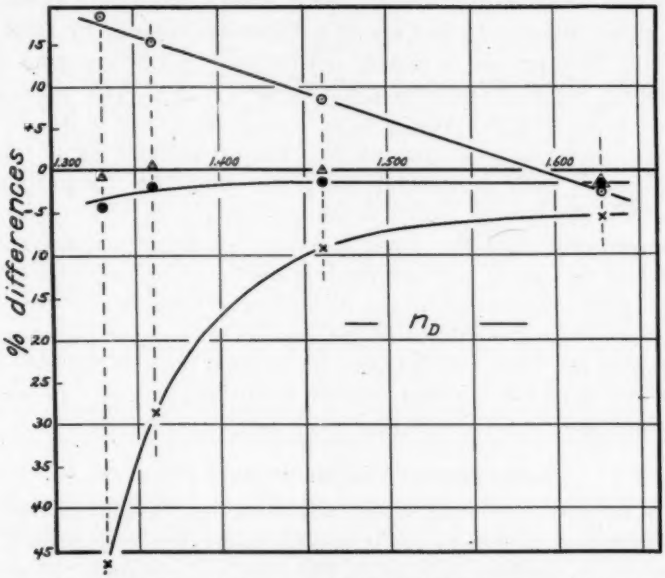

FIG. 2. *Percentage differences from accepted values of the dispersions, as dependent on* n_D. *(1)* x, *by achromatization with C-prisms, using the drum reading, and with chart values of A and B (1,–4, 5, 6; 2,–4, 7); (2)* ⊙, *with values of A and B from the Abbe equation, achromatic readings from the drum, and taking* $2k = 180'$ *(2,–3, 6; 3,–11, 13, 14; 4,–11); (3)* ●, *same, but taking* $2k = 190'$ *(4,–5, 6); (4)* Δ, *same, but with* $2k = 188.5'$ *(av.) (4,–8, 9).*

To summarize, the calculated values of Δn (3, –9, 10), derived from the calculated values of A, B, and Δe (2, –3, 6; 3, –6), all agree, upon checking, with book values to well within 1 unit in the 4th decimal place (3,–10). From the calculated values of A, B (2,–3,6), however, but observational values of Z_a (4, –11), there are differences of 8 or 10 units in the 4th (3,–14). Adjusting the value of $2k$ (4,–3) does not give completely uniform results. It appears that improvable limited precision in the particular instrument accounts for an appreciable part of the error in Δn up to 18 percent (3, –14), remaining after the chart values of A and B

were corrected. Graphically, the improvement in the agreement of the observational with the check values of Δn, when the chart values of A and B are discarded in favor of those calculated from the Abbe equation, is shown in Fig. 2.

APPLICATION OF DIFFERENTIAL FORM TO THE WAVE LENGTH INTERVAL, F TO C

In measuring Δn by achromatization, Abbe avoided the experimental use of two different λ's and also of a dispersion formula, by measuring Δe with the C-prisms. In making this improvement he applied a differential Eq. (4), to the interval of wave length, F to C. This approximation results, with the present data, in no greater error in Δn than 0.3 unit in the 4th decimal place (3,–10). The actual error due to this approximation alone is probably much less than this. Its smallness is doubtless attributable largely to the fact that Δe for the test substance is known experimentally, being measured on the refractometer itself. Although the Cauchy shorter formula is applicable for interpolation with rather high accuracy (see below), its differential form, $dn=(-2b/\lambda_D{}^3)d\lambda$, when applied to the interval F to C, gives errors in the dispersions of somewhat less than 5 units in the 3rd decimal place (CS_2), increasing with increasing index, or more exactly, a constant error of -13 percent. Algebraically this error is $[2\lambda_F{}^2\lambda_C{}^2/(\lambda_F+\lambda_C)]/(1/\lambda_D{}^3)$.

APPLICATION OF CAUCHY SHORTER FORMULA

The method of monochromatic calibration described previously gave the dispersion (p. 494, r7) quite satisfactorily, even with some uncertainty in the determination of $2k$. The Cauchy equation in the simpler form, $n=a+b/\lambda^2$, is useful for this type of calibration. The constants are found from the indices at two different λ's, as is well known. The formula was tested for the four liquids by substituting back into it numerical values of the constants obtained in this manner from data for the two λ's, F, C, (checked with Int. Crit. Tables), applying the formula to λ_D and solving for n_D, which then was compared with its book value. The differences were in all cases less than 5 units in the 5th decimal place.

CONCLUSION

Basically, the Abbe refractometer with compensating prisms is a widely useful instrument. Its possible precision should not be impaired needlessly, in manufacturing mass methods or through too liberal application to many individual instruments of a blanket calibration chart for the dispersions. Specifically:

1. The chart values of A and B, in the case of a given instrument, were found to differ seriously from those calculated by the Abbe equation: A by a nearly constant amount of -11 units in the 4th decimal place, or about -4 percent, and B by amounts varying from $+37$ to -3 units in the 4th, or $+11$ to -1.5 percent approximately. The correction factor on the chart, for the second term of the working formula, did not improve the results, and had but little effect on them, less than 1 in the 4th decimal place.

2. With values of A and B calculated from the Abbe equation, and with experimental achromatic readings of the compensating prisms, the differences from book values previously found in the dispersions, were reduced from the range -46 to -5 percent, to the range $+18.4$ to -2.6 percent. These remaining differences are attributable in part to insufficient mechanical precision of the particular instrument, and in part to a possible error of 5 or 6 percent in the determination of $2k$.

3. The constants β, N, ΔN, k, need to be known precisely for each refractometer. The calculated values of A and B must conform quite exactly to them. Where $2k$ and β are known to the nearest minute of arc, and N and ΔN to say 5 in the 5th decimal place, the resulting calculated values of A and B together with the achromatic reading Z_a of the compensating prisms, should give the dispersions usually to about 5 percent or less. By this method of achromatization and under best experimental conditions, Δn should be obtainable to almost the same precision as n_D itself, say to within 3 or 4 in the 4th decimal place. Indications were noted that Δn might be measured to about 1 percent with an instrument of attainable precision. Obviously, judged from the algebraic expressions (9), a considerable amount of calculation is necessary to prepare for a given refractometer a calibration chart with values of A and B, as functions of the D-index of the test substance, in sufficiently small steps of n_D.

4. With the high-index glass in the prism of a modern Abbe refractometer, the approximations in the Abbe equation for dispersion are negligible.

The writer acknowledges here the assistance of Professor B. Kurrelmeyer, Columbia University, in presenting the previous paper for him in his absence, before the American Optical Society, February 1931, and of Mr. L. H. Humason, technician at the University of California at Los Angeles, for an excellent photographic copy, reproduced in that published paper, of the wood cut of the Abbe refractometer in the paper by Pulfrich. Also, thanks are due Professor W. C. Morgan, of the Department of Chemistry of this institution, for several samples of test liquids.

A SIMPLIFIED METHOD OF PREPARING SCHUMANN PLATES

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ABSTRACT

A technique for preparing durable Schumann plates is described enabling them to be prepared with comparative ease. A new method of supersensitizing, and various technical points relating to their handling are summarized.

§1

For the photography of the spectrum below λ2300 the ordinary gelatine-bromide plate is quite unsuitable on account of the absorption which gelatine exercises on light of these short wave lengths. This lack of sensitivity in the short wave region may be obviated by coating the emulsion with some fluorescent substance which converts incident short-wave radiation into light of lower frequency to which the emulsion is sensitive.[1]

But if the maximum resolving power and sensitivity are required, the use of plates prepared with the minimum quantity of gelatine according to the prescription of Schumann[2] is still absolutely essential, for any fluorescent film causes blurring of fine spectral lines by sideways spreading of the fluorescent light.

It is the purpose of this paper to give an account of a simplified method of preparing Schumann plates rather more durable than the original type, to describe a new method of supersensitization, and to mention what variations in technique are permissible. The method has the advantage that it can be applied to the preparation of either plates or films. Although excellent commercial plates are now obtainable, it is a great advantage to the spectroscopist to be able to prepare, at short notice, emulsions whose characteristics are appropriate to the work in hand. The idea is very prevalent that their preparation is inordinately difficult; but we believe that if the process described below is carried out, it will be found comparatively easy to make durable and satisfactory plates. The method was developed some years ago by one of us

[1] Cf. Lyman, "Spectroscopy of the Extreme Ultra-violet" (Longmans, 1928) p. 61, for description and references. Recently the Eastman Kodak Laboratories have prepared a special sensitizer several times more sensitive than any oil with which we are acquainted. But see Allen and Franklin, Bull. Am. Phys. Soc., April 1932.

[2] V. Schumann, Ann. d. Physik *5*, p. 349; 1901.

(H)[3] and briefly described, but it seems worth while to describe the method in somewhat greater detail and to give the benefit of a somewhat extended experience.

§2.

In the preparation of ordinary Schumann plates a very dilute solution of gelatine containing suspended silver bromide is spread on a glass plate and allowed to stand until the bromide has settled on the glass surface, after which the spent liquid is drained off, leaving a very delicate layer of bromide bound by a minimum quantity of gelatine. The plates to be described differ in that the silver salt is deposited *on top of* a thin layer of clear, solid gelatine which is in turn carried by the mechanical support of glass or celluloid.[3a] This artifice gives a very durable bromide surface, for the grains of silver bromide apparently stick firmly to the gelatine layer, much as granite chips stick to a tarred road.

To prepare the glass-and-gelatine support it is most convenient to take ordinary unexposed gelatine-bromide films or plates and fix them thoroughly in acid-hypo containing alum as a hardener. The plates should be left in the hypo for some time after they have become clear in order to avoid 'frilling' of the gelatine at the edges during the long washing to which they are subjected. They are rinsed after removal from the acid bath and left to wash for 8–10 hours (conveniently overnight) in a stream of running water. They are then removed, rinsed in distilled water to remove any mineral salts left by the tapwater and placed to dry in a dust free atmosphere. During this process they must not be contaminated by traces of developer or of ordinary photographic solutions, and they must be touched only with freshly washed hands. Celluloid films are better not dried completely, but only freed from droplets of surface water, otherwise they are apt to warp during the subsequent processes.

During the deposition of silver bromide these plates are supported on individual trays. They are made by taking pieces of reasonably flat sheet glass and trimming them so that they are about 1 cm shorter and 1 cm narrower than the plates to be prepared. They are provided with glass supports (Fig. 1) made by sticking pieces of *round* glass tube 7 mm diameter to their under surface with sealing wax, so that the upper surface is level when the supports rest on the levelled table. It is im-

[3] Hopfield, Phys. Rev. *20*, p. 275; 1922. It is believed that this is the first account of the preparation of Schumann celluloid-films.

[3a] Schumann employed a gelatine substratum for his early gelatine-free emulsions, but does not appear to have used it for his improved gelatine plates.

portant that the glass tube used should be fairly free from taper, and that each tray should be provided with supports snapped successively from the tube so as to minimize what taper exists. The supports must also not project beyond the edges of the table; otherwise the layer of emulsion, which is retained by surface tension, will probably run off.

The levelling table which supports the small trays is made from a slip of plate glass about a meter long (the length depends on the number of plates to be prepared) and about as broad as the plates are long. It is supported firmly a few inches above the working bench by wooden blocks glued to its ends, and is carefully levelled before preparing a batch of plates. A glass tube (shown in Fig. 1) is waxed along one long edge of the table to act as a tripping rail. The individual trays, spaced by an

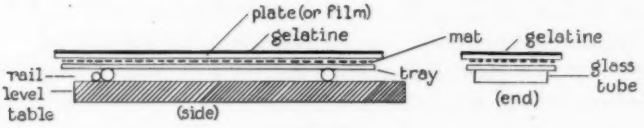

FIG. 1

inch or over are pushed up against the rail, as shown, and are covered with filter paper mats cut to their exact size. The paper is moistened with water and the clear plates or films, with their gelatine surfaces upwards, are placed on the mats. The plates must be placed symmetrically on their trays, giving each edge the $\frac{1}{2}$ cm overhang allowed in the design; otherwise if the edges of plate and tray come into contact the emulsion will run off at that point when one attempts to coat the plate. The plates adhere quite firmly to their trays, being held by the liquid film. The filter paper retains the moisture during the period while the emulsion is settling, but it is worth noticing that when celluloid films are being prepared a fine grained filter paper should be used, otherwise the under surface (which is coated also with gelatine in this case) will be stamped with an unsightly chequer pattern from the grain of the paper. Celluloid films also should be so moist as to lie quite limp when placed on their trays, otherwise they are apt to warp during the subsequent processes. This moistness sometimes makes it more difficult to spread a thick coating of emulsion, without its running off at the edges. In this case one uses dry films which are placed on their trays immediately before spreading the emulsion, so that they have no time to warp. Also the celluloid must not be punctured with a pin during the drying for obvious reasons. In all subsequent operations the tray provides a convenient handle for the plate, making it unnecessary to touch the later at all until the emul-

sion has been drained off and the plates are stripped from their trays for drying.

§3.

The plates are now ready for coating. The emulsion is the same as that described by Schumann in his original paper.

Solution A		Solution B	
K Br	9.0 g	$AgNO_3$	11.25 g
Gelatine (Nelson No. 1)	4.5 g		
Distilled water	60 cc	Distilled water	60 cc

About 10 percent more bromide may be used, and a trace of KI (about 0.2 g in Solution A). The larger quantity of bromide makes the emulsion less liable to fog while maturing, and the iodide appears to diminish the likelihood of fog at the higher speeds, but we cannot be sure of this last suggestion.[4]

The gelatine is allowed to stand for half an hour until completely swollen, and the flask containing it is immersed in a water bath at 60°C until the gelatine dissolves. Floating dirt is then strained off through cheesecloth, and both solutions are brought to 60°C in a water bath preparatory to mixing. The mixing must be done by red light, which may however be very strong—a gas filled 100 cp lamp behind ruby glass is quite suitable. The nitrate solution is added a little at a time to the gelatine-bromide with continual shaking, so that at no time can the silver nitrate concentrate locally in the solution. This concentration, if it occurs, tends to produce fog.[5] When all the nitrate has been added the flask is closed with a clean cork and vigorously shaken. It is then replaced in a water bath, brought to 60°C, or less, and poured into a good thermos bottle (which has been scalded out with water at 60°C), corked up, and left to mature in the dark.

The time and temperature of maturing are very important. If matured too long the emulsion is 'grainy' and fogged, if for too short a time it is insensitive. Schumann recommends ½ hour at 60°C, but we have found that 50°C for a somewhat longer time gives cleaner plates. This difference of practice is perhaps accounted for by the difference between American and German indoor temperatures. While the emulsion is set-

[4] Our experience is somewhat at variance with Schumann's. It appears quite possible to produce bromiodide emulsions with desirable characteristics, and indeed one of the cleanest and fastest batches we prepared contained 2 percent KI in solution A. But there is no doubt that great care is required in developing plates containing iodide, otherwise the grain size becomes unduly noticeable. Moreover, the plates pass more quickly than the bromide emulsions from a hypersensitive to a fogged state.

[5] Cf. Handbuch der Wiss. u. Angewand. Photographie *IV*, R. Jahr p. 218; Springer, 1930.

tling, maturing still goes on to some extent, in spite of the lower temperature, because the protective colloid, (gelatine) is at so low a concentration in the diluted emulsion. This after-maturing in our case took place at a temperature of 22°C. Under these circumstances we found that maturing temperature of about 50°C for an hour gave suitable results. The liquid emulsion was poured at about 55°C into the thermos flask and allowed to stand for this period, during which time its temperature fell to about 47°C. A trial will decide the matter if settling temperatures very different from 20°C prevail.

The emulsion is then decanted from the flask into an evaporating basin (care being taken not to disturb the larger grains of bromide which settle to the bottom of the flask), chilled to a jelly on ice and cut up with a horn spatula into small lumps. It is then placed in a bag of cheesecloth and left to wash in a stream of running water for three hours or more; if possible overnight. The water should not be warmer than 14°C or the jelly will dissolve.

FIG. 2

If the laboratory water supply is too warm for safety the emulsion may be washed in a beaker containing 2 l of iced, distilled water which is changed ten times at quarter hour intervals. This process removes the potassium nitrate and the excess of bromide. The jelly is then dissolved in a liter of boiled water (tap water, if not too hard, is quite suitable) which has been cooled to 60°C. It is then filtered twice through a plug of glass wool into a shallow dish and is allowed to stand for 3/4 hour after which the supernatant emulsion is decanted off. This settling removes the larger grains of bromide which otherwise pepper the developed film with dark spots. The emulsion is then ready for spreading. Air bubbles must be avoided when pouring the emulsion.

For coating the plates a pipette is most convenient. The jet should be made trumpet shaped (Fig. 2) so that the velocity of efflux is small, otherwise the liquid shoots off the edge of the plate. The emulsion is run on the plate and the pool is gradually spread by moving the delivery jet all over the plate. It is important to spread the globule uniformly from its centre. If 'bays' are allowed to develop a bubble of air is often

enclosed which leaves a bare spot on the finished plate. The nozzle of the pipette should touch the plate as little as possible.

When the emulsion is piled to a height of 2 or 3 mm it is spread to uncovered edges by the pipette[6] and if any runs off it is replaced from the stock. The advantage of individual tables for the plates is easily seen here, for it is possible to splash emulsion about without ruining the rest of the batch; the wasted emulsion merely drains off to the levelled table. The remaining plates are similarly coated; and the bromide is then left to settle in the dark for three or four hours.

Now follows the most delicate part of the work. The spent emulsion must be drained off without rupturing the film of precipitated bromide. A glass rod is laid vertically against the edge of the plate, thus breaking the liquid surface film and allowing the liquor to drain off very slowly. To hasten the process of draining a spatula is placed under one end of

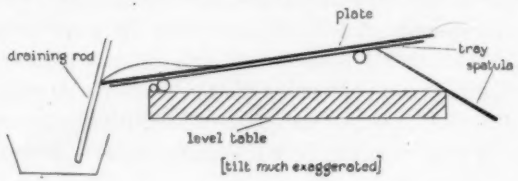

FIG. 3

the individual tray (Fig. 3) and the end of the plate furthest from the glass rod is raised 1 or 2 mm by levering the spatula on the edge of the lower table. Draining at this small angle is continued for about thirty seconds, when the spatula is slowly raised until the table can be propped up with a cork. During this operation the plate itself must under no circumstances be touched with anything but the glass rod—a finger, or even a spatula touching the edge will give a disturbance of the liquid which will produce long streaks on the bromide surface. The next plate is similarly treated, and so on till all the batch are drained. It is worth doing this operation very slowly; if the process is performed hastily the bromide is dislodged by turbulence, and patchy plates result. The few drops of liquid which still remain on the lower edge of the plate are touched off with the glass rod and each plate is separately brought to the vertical portion, slid from its tray and reared up to dry, emulsion upward, in a suitable closet whose floor is covered with filter paper. During

[6] The laborious bevelling of the edges described by Schumann appears quite unnecessary in order to retain the layer of emulsion on the plate. The surface tension readily retains a layer of this thickness without trouble.

these processes the plate must always be kept with the same edge down and handled by the edges only. If the liquor flows back over the drained coating it is apt to produce patchiness.

When the plates are dry they are packed in pairs face to face, spaced by runners of paper at their edges, for although they are rather less sensitive to pressure marks than ordinary Schumann plates they are readily fogged by any kind of abrasion.

Celluloid films are treated in exactly the same way except that when they are removed from the tables they cannot be handled by the edges on account of their flexibility. They are therefore stripped from the filter-paper mat by seizing one corner delicately with glass—or bone-tipped forceps. During the drying they are hung from wooden clips and they must be packed in a light tight box whose edges are grooved to receive them. If they are warped with the emulsion on the concave side and packed face to face they will store quite conveniently.

The plates so prepared may be used at once. They are slow and 'contrasty' and behave rather like lantern slide, or 'process' plates. A suitable developer is the Eastman M-Q formula for a process developer, somewhat diluted (say 2:1) and used at about 15°C. With this treatment they give clear whites and dense blacks with a fine grain and are very suitable where speed is no object.

But for many purposes a faster plate is required. The plates increase in speed very much as they are stored, but the optimum state is only obtained two months after manufacture. This maturing process may be much curtailed by baking the plates at 60°C for a day or two.[7] In some cases the baking brings up the speed about fifteen times (measured by the time required to give a completely exposed spectrogram under standard conditions). The plates are simply placed, in their cardboard carton, into an electric oven which can be maintained at about 60°C (not more). If plates for immediate use are required the process of maturing must be checked by exposing and developing small test-coupons from the batch at intervals during the baking, for if the heating is protracted unnecessarily the plates become fogged. Tests should be made after the 36th hour at intervals of 6 hours, and as soon as a trace of fog appears at the edges of the plate the process must be interrupted. Generally speaking the plates never fog with less than 48 hours heating, but almost always at 72 hours. The plates which are just beginning to fog are extremely fast (about as fast in the near ultraviolet as a fast gelatine-

[7] This method has the great advantage over Schumann's method of bathing in warm water in that it does not produce stains on the plates.

bromide emulsion) but they usually fog so much after a week's storage that their general usefulness is much impaired. For most purposes it is best to bake for 48 hours and let the rest of the maturing take place at room temperature. The plates may then be stored for a month or two before they begin to fog, all the while increasing in speed.

These fast plates are best developed (as recommended by Lyman)[7a] in Hauff's Ortol-Potash developer,[8] used at 4°C. They are developed by inspection; about 3 minutes is usually required. Although the Eastman M-Q process developer may be used, we believe, as Lyman found, that the Ortol developer produces finer grain in the developed image, has less tendency to fog, and from the slowness of its action that one can force development more safely in order to bring out detail.

The plates are fixed in hypo, and must then be washed for at least half an hour in running water on account of their substratum of gelatine. The films are very durable and may be swabbed with a loose mop of wet cotton in order to remove dust after the washing.

After drying in the usual way contact prints may be taken from them without injuring the surface, and indeed, so durable are they that they may even be vigorously rubbed with the thumb. The only effect of such treatment is to burnish, and perhaps to scratch a little the silver of the image.

It may be that at very short wave lengths the substratum of gelatine may diminish the sensitivity of these plates, but they are quite as sensitive as commercial Schumann plates down to 500A, and as to grain size and clearness of working they are perhaps better than most batches we have tried.

The preparation of such plates may appear somewhat tedious from the description given above, but in practice only a few hours of actual work are involved and minor deviations from the process described are quite permissible. Reasonable cleanliness is essential, but 'surgical' cleanliness is by no means necessary, and all operations may be conducted in a dark room which has been used for the ordinary photographic processes of development and fixing.

[7a] Lyman, reference 1, p. 153.

[8] Ortol-Hauff.

Solution A		*Solution B*	
Water	1000 cc	Water	1000 cc
Potassium metabisulphite	7½ g	Potassium carbonate (dry)	60 g
Ortol	15 g	Sodium sulphite (Crystalline)	180 g

1 part solution A, 1 part solution B, 2 parts water. Ice q.s. A 10 percent solution of KBr should be added up to 1 drop per cc for old plates. During development a lump of ice should be held in the developer at one end of the dish.

THE USE OF PLANE TRANSMISSION GRATINGS

By H. M. Reese
[University of Missouri, Columbia, Mo.] Received June 11, 1932

In an article in this journal for July 1931, under the title *Grating Theory*, H. S. Uhler brings out some interesting points in connection with plane transmission gratings. In order to avoid the need to either measure the angle of incidence or set the grating exactly normal to the collimator, he derives a pair of formulas by means of which the quantity $n\lambda/\delta$ is calculable in terms of the right and left angles of deviation, β' and β, measured for the same wave length λ and spectrum order n. These formulas are:

$$n\lambda/\delta = \cos\Phi \sin \tfrac{1}{2}(\beta' + \beta)$$

$$\tan\Phi = \sin \tfrac{1}{2}(\beta' - \beta)/(2 \sin \tfrac{1}{2}\beta' \sin \tfrac{1}{2}\beta).$$

The somewhat increased labor of calculation is compensated by the fact that to determine β' and β only three circle readings are necessary, and the use of a Gauss eye-piece is dispensed with.

Taking λ as the mean of the principal sodium doublet, $n=2$, and $\delta = 2.54 \times 10^{-4}$, Uhler calculates, for various angles of incidence, the errors in $n\lambda/\delta$ that result from an uncertainty of one second of arc in each of the three angle readings. In general, these resultant errors are least when the angle of incidence, i, is zero. In particular, the calculated value of $n\lambda/\delta$ is wholly unaffected, for $i=0$, by an error in the setting on the central image.

This of course is as it should be, since for $i=0$ β' and β are equal, $\Phi=0$, and the first of his two formulas becomes the ordinary equation for normal incidence, expressed in terms of the average of the right and left angles of diffraction, which average is most conveniently found by measuring their sum directly, thus avoiding the need to locate the central image. However, the facts suggest that Uhler might have carried his analysis a step farther, enquiring into the effect of making the angle of incidence small and treating it as if it were actually zero. If such an approximation proves permissible, it is only necessary to use the Gauss eye-piece enough to ensure that the angle i is sufficiently near to zero, and then measure the double angle of diffraction (or deviation) and the calculation of the wave length takes the simplest form. Only two circle readings are necessary.

That such a procedure *is* permissible can easily be shown. Uhler's first equation, expressed in terms of θ' and θ, the angles of refraction, instead of β' and β, becomes

$$n\lambda/\delta = \cos\Phi \sin \tfrac{1}{2}(\theta' - \theta)$$

and the angle Φ, which Uhler defines as being $i+(\beta'-\beta)/2$, becomes

$$\Phi = (\theta' - \theta)/2.$$

If i is nearly zero, θ' and θ are nearly equal, and Φ is a small angle. It is not hard to prove that

$$\sin\Phi = \sin i/\cos \tfrac{1}{2}(\theta' + \theta)$$

showing that Φ, although larger than i, is not much larger unless θ' and θ are rather large angles, that is unless a high order of spectrum is used, or the grating has a small value of δ. Taking the values of λ, n and δ used by Uhler in calculating errors, it is found that if the angle of incidence is made equal to one degree, $\theta' = 28°46'49''$, $\theta = 26°31'21''$, and $1-\cos\Phi = 0.00018$, so that by ignoring the value of the angle of incidence we should make an error of 0.018 percent, about the same as is shown by Uhler's calculations for the case of minimum deviation when an error of $20''$ is made in determining the angle of minimum deviation.

The practical procedure would then be to set the telescope and collimator in line, then set the grating so that the Gauss eye-piece shows that the angle between the grating normal and the telescope axis is not more than a few minutes (this *does* require a Gauss eye-piece), and finally measure the double angle of diffraction, which has, as we have seen, a stationary value at $i=0$. The sine of half this angle gives the value of $n\lambda/\delta$.

Uhler's paper is concerned only with gratings ruled on parallel plates of optical glass. Actually most plane transmission gratings now used are probably replicas. Although the best grade replicas are mounted on plates with fairly good optical surfaces, they usually have enough taper to show double images by reflection from a distant source.

In using such gratings it is common practice, if the highest precision is desired, that the ruled face should be next to the telescope. For in that case the only effect of the prismatic action of the glass will be to make the angle of incidence slightly different from what it appears to be. If one uses Uhler's method, the angle of incidence does not enter into the calculations. If the method advocated in this paper is used, an uncertainty of a few minutes of arc in the value of i is immaterial. On the

other hand, if the light is subject to prismatic refraction *after* it has been diffracted, errors might come in. For very oblique passage through a prism of small angle, the deviation produced may be many times greater than the angle of the prism, and the three rays considered in Uhler's method, or the two used in the method here advocated, emerge at quite different angles.

The Microscope. By Simon Henry Gage, Emeritus Professor of Histology and Embryology in Cornell University; Ultraviolet (fifteenth) edition. viii+589 pages. The Comstock Publishing Company, Ithaca, N. Y. $4.00.

The fifteenth edition of this classic, yet ever modern, treatise on the microscope has been given by the author the appelation "Ultraviolet Edition," largely because of the introduction into this edition of a wholly new chapter entitled "The Ultraviolet Microscope and Physical Analysis." The remainder of the book has been completely revised, rearranged and otherwise brought up to date. For example, a special attempt "has been made in this edition to encourage the study of living and fresh tissues and organs by means of the physical analysis made possible by the perfected dark-field, the ultra-violet and the polarizing microscope, and the micro-spectroscope," since many investigators have become "so obsessed with the importance of general and differential staining . . . that they have come to neglect, and perhaps even forget that the observation of living and fresh objects may possibly give a truer conception of them than the highly artificial pictures produced by chemical fixation and gorgeous coloring." (Quotations from preface.)

Previous editions of this book are so well known that a description of the contents and method of treatment of the present edition is quite unnecessary. Suffice it to say that throughout the book Professor Gage discloses his profound knowledge of the fundamental physics upon which the microscope in its various forms is based. When, in addition, one recalls his international standing in his chosen field of science, it is no wonder that THE MICROSCOPE has become the standard of reference wherever the instrument is used. Not only workers in those pure and applied sciences, where the microscope is employed so extensively, but physicists as well will find in this book a mine of information.

F. K. Richtmyer

Vision and Colour Vision. By R. A. Houstoun, University of Glasgow. Longmans Green and Co., 1932; 234 pages, 102 illustrations.

When Helmholtz made his famous criticism of "The Eye as an Optical Instrument," saying he would send it back to the maker because it exhibited every conceivable defect, he spoke of its failings as an image forming device. Had he gone farther and discussed its failings as a *radiometer* he could have been even more severe. As an instrument for measuring and analyzing radiation the human eye has every defect of the worst photosensitive devices known. It has lag, fatigue, leakage, poor recovery, non-proportionality

of response, and ambiguity in its indications, especially as a frequency (color) indicator. Unlike the dioptric behavior of the eye, which is very completely analyzable into factors exhibited by inanimate lens systems, the physics and chemistry (to say nothing of the physiology and psychology) of vision, and particularly color vision, are far from being elucidated, and provide a never ending field for experimentation and theorizing.

Dr. Houstoun's interesting little book deals almost entirely with the problems presented by the eye as a light sensitive instrument, and contains a surprisingly large amount of information on recent studies along these lines, a large part of which are due to the author himself. It will appeal chiefly to the physicist, since not only is the experimental material largely the product of a physical laboratory, but the point of view in the theoretical interpretation is entirely physical. Obviously the whole explanation of vision cannot be expected along merely physical lines; physiological and particularly neurological processes must play a large part. However, the possibility that the processes in the retina at least are susceptible of photoelectric explanation is a sufficiently attractive one to warrant intensive exploration.

Perhaps the most significant development in recent research in vision in the introduction of considerations of probability distributions. A striking example of this is Hecht's work on visual acuity, from which it appears that the increase of visual acuity with illumination is elegantly explained as due to an increase in the number of receptor elements coming into play as the illumination of the retina rises. The long known roughly logarithmic relationship between visual acuity and illumination turns out to mean that the numbers of elements of an "all or none" response characteristic having successively higher thresholds occur according to a Gaussian probability distribution. The receptor elements constitute a population with properties ranging about a mean in just the same way that a vast array of other properties group themselves in statistical surveys. Another manifestation of the same fundamental fact is the variation of sensation with intensity which has figured so prominently as Fechner's law. Dr. Houstoun makes clear that this again is to be accounted for by the addition of excitations of new thresholds distributed according to the same probability law. The same receptors must of course be responsible for the variation of acuity and luminous sensation with illumination, and the long known parallelism between both function of vision is thus explained.

Another field in which probability distributions must now be recognized is in color vision. The early classification into simple trichromats, dichromats, and monochromats, based on altogether too few observations, apparently must be completely given up. Instead it appears, from several methods of analysis of color vision, that individuals vary from normal in several different ways, such as actual deficiency of color vision, and fineness

of discrimination without necessary deficiency, but that those variations do not fall into definite groups. They are again arranged about the normal according to a probability curve.

These considerations lead Dr. Houstoun to be iconoclastic with regard to the Young-Helmholtz theory of color vision, although he recognizes clearly that the trichromatic color mixture phenomena must be explained by any alternative theory. An apparently vital flaw on the three receptor theory, discussed at length by Dr. Houstoun is that the law of intensity summation of three excitations cannot hold, according to the population of different thresholds idea, if these are very different in luminous sensation value, as the red, green and blue sensations are ordinarily assumed to be. This objection would appear to be met by Hecht's theory of color vision (unfortunately not mentioned in this book) in which the three excitations are always of nearly equal value, the sensation of color being due to residual differences—a kind of "chromatic aberration" of the excitation curves. Dr. Houstoun inclines strongly to the view that luminosity and color are quite separate functions. He presents an interesting, if somewhat sketchy theory of vision, according to which retinal nerve synapses of two sorts, red-green and yellow-blue, trip one way or the other depending on the frequency of the light, thus giving color sensations superposed on an intensity sensation. He shows that these four color responses can yield the trichromatic mixture relations.

A discouraging feature of speculation and theorizing in vision and color vision is that there exist such a multitude of experimentally observed phenomena which appear quite superfluous and serving no useful purpose for the function for which the eye exists, but which rise up to refute any simple theory which may be constructed. It appears that nature had no clear-cut method of approaching the problem, but has used all sorts of expedients, sometimes several in different parts of the visual system to do similar things (witness binocular color fusion, in spite of evidence that color fusion occurs in the retina). The bewildering anomalies of color reversal in intermittent vision, after images and their drift across the field of view, simultaneous contrast, adaptation, flicker phenomena, and a host of other obscure effects, to say nothing of the whole field of color blindness; have called forth many *ad hoc* theories which only break down when attempts are made to widen their scope. With regard to the more complex aspects of vision, Dr. Houstoun takes probably the only position on which progress can be made by any less universal genius than Helmholtz, namely, "I doubt whether it is advisable to spend time on this field until the explanation of the simpler phenomena of colour vision is on a secure ground."

HERBERT E. IVES

The White Dwarf Stars. The Halley lecture delivered by E. A. Milne, Rouse Ball Professor of Mathematics in the University of Oxford, 32 pages and one diagram. Oxford at the Clarendon Press, $0.85.

A most interesting lecture on a fascinating subject presented to appeal to the educated layman, no less than to those conversant with modern astrophysical developments.

To present to the layman the results of the abstruse investigations into the physical conditions existing in the interiors of the stars; and even to indicate the sequence of events which may plausibly lead to the cataclysm in nature which results in the formation of a dwarf star, and even more to the rarer event of the formation of such a system as the Sirian system in which we have a binary star consisting of an ordinary star and a white dwarf, is no mean achievement.

To present, at the same time, these results with an outline of the methods of attack on the problems involved; and to do it in such brief compass and in such a manner as to sum up the present status of the problem for the expert in the field, is an achievement only possible to an advance guard in this field.

To present in briefer form what the author has given in this lecture would be an impossible achievement, for the lecture itself is a review of the results of his own and others work in this field.

Perhaps the most interesting phase of the lecture is that Professor Milne presents a theory which accounts for white dwarf stars as the result of that cataclysmic event which we call a Nova and at the same time may account for variable stars and for such binary systems as those of Sirius and Procyon in which we find one component an ordinary star similar to our Sun, and one component a white dwarf. It is possible that all binary and multiple systems of stars may be accounted for by the theory presented, though Professor Milne does not suggest this.

The author relates Halley's pioneer work on the motion of Sirius, and Bessel's prophetic remarks connecting his discovery of the periodically variable proper motion of Sirius and Procyon and Tycho's Nova, with the important developments of the present day.

S. L. BOOTHROYD

IRWIN GILLESPIE PRIEST
1886–1932

IRWIN G. PRIEST

In the death of Irwin G. Priest the Optical Society loses one of its outstanding figures. A charter member, for a long period secretary, and later president of the society, he contributed his services continuously and unstintingly to its advancement, while his scientific work was an ornament to it.

Priest's whole scientific life was passed at the Bureau of Standards and practically all of his work lay in the field of color measurement and specification. Entering the Bureau in 1907 immediately after graduating from Ohio State University, he was for a time personal assistant to the director, Dr. Stratton, who endeavored to carry on experimental work in optics in spite of the ever increasing load of administrative work. The field of interferometry to which he was thus introduced formed the subject matter of Priest's earlier published work, in which he made precise determinations of the wave lengths of the neon lines and devised novel methods of wave-length measurement. From this he soon turned to the difficult and technically very important subject of color measurement, which, as chief of the Colorimetry Section of the Bureau, he investigated from all angles, ranging from the physiology and psychology of color vision to the design of new instruments and the development of practical methods of rating the colors of fats and oils. Subjects which particularly interested him were the measurement of color by polarimetric methods, analysis of color in terms of hue, luminosity and purity, and the proper specification of an average daylight or a white most suitable as a basis for colorimetry. This latter research was one on which he spent many years of labor, and he left unpublished an exhaustive treatise giving the results of his studies and conclusions. Perhaps his most important purely scientific work was on the relative saturation of the different parts of the spectrum, which has played a vital part in recent theories of color vision.

As a scientific investigator and laboratory director Priest's methods were a model. He possessed great ingenuity in devising special optical instruments to perform complicated measurements with a minimum of distracting physical labor, at the same time eliminating with meticulous care all sources of error. He was wonderfully patient, persistent and thorough in his experimental work, much of which, particularly in the realm of psycho-physics, remains unpublished because of his dissatisfaction at calling any job done as long as any loophole of alternative

interpretation remained. His industry was prodigious, and he never shied at the accumulation of enormous masses of experimental data and their subsequent exhaustive tabulation and analysis. His records were always arranged in a thoroughly systematic and attractive form so that a visit to his office to discuss any topic on which he had worked was a joy. This genius for order and clarity he carried to his official positions and thereby contributed greatly to his success as an officer and member of many committees in the Society. As secretary he introduced, in the face of general misgiving as to its feasibility, the practice of printing full abstracts of papers in the programs of meetings, a move later followed by the Physical and other societies with entire success.

In addition to the scientific work published under his own name, Priest must receive credit for numerous important investigations carried on under his direction and inspiration. Among these should be remembered the development of filters for the accurate reproduction of black-body and daylight energy distributions, the definitive determination of the visibility of the spectrum, and the compilation and correlation of data and methods for the computation of trichromatic coefficients. The results of these investigations have been incorporated in the standardizing legislation of such bodies as the International Photographic and Illumination Congresses. One of Priest's last official duties was attendance at the International Illumination Congress in London last summer, where the topic of color measurement and standardization was a major issue and to which he was able to contribute weightily.

Over and above his scientific achievements, Priest will always be remembered by those who came in contact with him for his winning personality. He was strong in argument, delighting in getting at the philosophical basis of his subject, persistent in advocating his own views but always preferring to win his point by personal persuasion rather than by public controversy. Thus he wrote, sparing neither time nor labor, long letters eminently worthy of publication as scientific papers, which he mimeographed and sent to interested parties, frankly discussing the weaknesses and errors of proposed instruments, methods or systems of nomenclature, thereby seeking to bring about agreement before an issue was publicly joined. He possessed a delightful sense of humor, a contagious enthusiasm and a thoughtfulness for others which made him welcome in all circles. He will be sadly missed, both for the scientific work he was preeminently fitted to carry forward and for his personal traits, which endeared him to all who were associated with him.

H. E. IVES

BIOGRAPHICAL DATA

Irwin Gillespie Priest, physicist, was born near Loudounville, Ohio, January 27, 1886, the son of Morgan A. and Julia A. (Schauweker) Priest. He graduated from the Ohio State University with the degree of B.A. in 1907, and was immediately appointed on the staff of the Bureau of Standards. He married Edna Ryan of Washington, D. C., June 26, 1917. He died in Washington July 19, 1932.

At the Bureau of Standards Mr. Priest had the rank of laboratory assistant 1907–08, assistant physicist 1908–15, associate physicist 1915–19, physicist (of various grades) 1919–32. He was made chief of the Section of Colorimetry in 1913. He worked at the Bureau as a Research Associate of the Munsell Color Company and the Munsell Research Laboratory for several periods in 1922–25, while on leave from Bureau duty.

He was a fellow of the American Physical Society and of the American Association for the Advancement of Science; a member of the Optical Society of America (Secretary 1921–24; Vice-President, 1926–27; President, 1928–29), American Psychological Association, Washington Academy of Sciences, Philosophical Society of Washington, Phi Beta Kappa, Sigma Xi, and Cosmos Club, and an honorary member of the American Oil Chemists' Society.

BIBLIOGRAPHY

I. PAPERS IN PUBLICATIONS OF THE BUREAU OF STANDARDS

A new method for determining the focal length of a converging lens. Sci. Paper 110, Bull. B.S. *5*, p. 483, 1908–9.

A modified method for the determination of relative wave lengths. Sci. Paper 142, Bull. B.S. *6*, p. 573, 1909–10.

Wave lengths of neon. Sci. Paper 179, Bull. B.S. *8*, p. 539, 1912.

A simplified formula for the change in order of interference due to changes in temperature and pressure of air. Sci. Paper 199, Bull. B.S. *9*, p. 479, 1913.

Measurement and specification of the physical factors which determine the saturation of certain tints of yellow (with C. G. Peters). B.S. Tech. Paper 92, 1917.

A new interferential dilatometer. Sci. Paper 365, S.P.B.S., *15*, p. 669, 1919–20.

Color and spectral composition of certain high-intensity searchlight arcs (with W. F. Meggers, K. S. Gibson, E. P. T. Tyndall and H. J. McNicholas). B.S. Tech. Paper 168, 1920.

An examination of the Munsell color system I. Spectral and total reflection and the Munsell scale of value (with K. S. Gibson and H. J. McNicholas). B.S. Tech. Paper 167, 1920.

The spectral distribution of energy required to evoke the gray sensation. Sci. Paper 417, S.P.B.S., *17*, p. 231, 1922.

Measurement of the color temperature of the more efficient artificial light sources by the method of rotatory dispersion. Sci. Paper 443, S.P.B.S., *18*, p. 221, 1922–23.

The Lovibond color system. I. A spectrophotometric analysis of the Lovibond glasses (with K. S. Gibson and F. K. Harris). Sci. Paper 547, S.P.B.S., *22*, p. 1, 1927–28.

Calibration of sixty-five 35-yellow Lovibond glasses (with Deane B. Judd, K. S. Gibson and Geraldine K. Walker). Research Paper 58. R.P.B.S., *2*, p. 793, 1929.

II. OTHER PAPERS. (Items starred are abstracts)

A condition limiting the precision attainable by increasing the "Order" in the "Method of Diameters" for wave lengths. Phys. Rev., *31*, pp. 95–96, 1910.

Certain peculiarities of the discrepancies among recent wave-length determinations. Phys. Rev., *31*, pp. 602–604, 1910.

"Triplet of Nicols" for photometry. Jour. Wash. Acad. Sci., *3*, p. 298, 1913. Also U. S. Patent No. 1,072,166.

Color specifications.* Rep. Proc. Fourth Ann. Meet. Soc. Cotton Products Analysts, p. 6, 1913.

The quartz colorimeter and its applicability to the color grading of cotton seed oil. Rep. Proc. Fifth Ann. Meet. Soc. Cotton Products Analysts, p. 22, 1914.

Report on investigations concerning the color and spectral transmission of cotton seed oil* (with C. G. Peters), Rep. Proc. Sixth Ann. Conv. Soc. Cotton Products Analysts, p. 67, 1915.

The Bureau of Standards contrast method for measuring transparency. Trans. Am. Ceramic Soc., *17*, p. 150, 1915.

A proposed method for the photometry of lights of different colors.* Phys. Rev., (2), *6*, p. 64, July, 1915; and *9*, p. 341, April, 1917; and *10*, p. 208, August, 1917.

The work of the National Bureau of Standards on the establishment of color standards and methods of color specification. Trans. Ill. Eng. Soc., *13*, p. 38, Feb., 1918.

A precision method for producing artificial daylight.* Phys. Rev., (2), *11*, p. 502, June, 1918.

The law of symmetry of the visibility function.* Phys. Rev., (2), *11*, p. 498, June, 1918.

A one-term pure exponential formula for the spectral distribution of radiant energy from a complete radiator.* Jour. Opt. Soc. Am., *2–3*, p. 18, Jan.–March, 1919.

A new formula for the spectral distribution of energy from a complete radiator.* Phys. Rev., (2), *13*, p. 314, April, 1919; and *14*, p. 191, August, 1919.

The spectral composition and color of certain high intensity searchlight arcs* (with W. F. Meggers, H. J. McNicholas, K. S. Gibson, and E. P. T. Tyndall, in cooperation with the Searchlight Investigation Section, Corps of Engineers, U. S. A.). Phys. Rev., (2), *14*, p. 184, Aug. and Sept., 1919.

Optical and photographic methods for the detection of invisible writing* (with E. P. T. Tyndall). Phys. Rev., (2), *14*, p. 188, 1919.

Report on the applicability of ultraviolet rays to signaling* (with K. S. Gibson). Phys. Rev., (2), *14*, p. 188, 1919.

A method for the color grading of red flares.* Phys. Rev., (2), *14*, p. 264, 1919.

The color of soya bean oil as compared with that of cotton seed oil. The Cotton Oil Press, Jan., 1920.

Report on investigations of the color and spectral transmissivity of vegetable oils.* The Cotton Oil Press, July, 1920.

Preliminary note on the relations between the quality of color and the spectral distribution of light in the stimulus. Jour. Opt. Soc. Am., *4*, p. 388, Sept. 1920.

Note on the relation between the frequencies of complementary hues. Jour. Opt. Soc. Am., *4*, p. 403, September, 1920; and *5*, p. 513, November, 1921.

A new study of the leucoscope and its application to pyrometry. Jour. Opt. Soc. Am., *4*, p. 448, November, 1920.

Report on calibration of sixteen Lovibond red glasses. The Cotton Oil Press, January, 1921.

A method of obtaining radiant energy having the visible spectral distribution of a complete radiator at very high temperatures. Jour. Opt. Soc. Am., *5*, p. 178, March, 1921.

The optical basis of Bittinger's camouflage paintings* (with M. K. Frehafer). Jour. Wash. Acad. Sci., p. 238, May 19, 1921.

A direct reading spectrophotometer for measuring the transmissivity of liquids.* Phys. Rev., (2), *18*, p. 127, August, 1921.

Measurement of the color temperature of the more efficient artificial light sources by the method of rotatory dispersion. Jour. Opt. Soc. Am. and Rev. Sci. Inst., *6*, p. 27, January, 1922.

The effect of various conditions upon the determination of the normal stimulus of gray* (with Casper L. Cottrell). Jour. Opt. Soc. Am. and Rev. Sci. Inst., *7*, p. 73, January, 1923.

Preliminary data on the color of daylight at Washington.* Jour. Opt. Soc. Am. and Rev. Sci. Inst., *7*, p. 78, January, 1923.

Apparatus for the determination of hue sensibility (wave-length differences perceptible by difference in hue) and the visibili.y of radiant energy.* Jour. Opt. Soc. Am. and Rev. Sci. Inst., *7*, p. 99, January, 1923.

The colorimetry and photometry of daylight and incandescent illuminants by the method of rotatory dispersion. Jour. Opt. Soc. Am. and Rev. Sci. Inst., *7*, p. 1175, December, 1923; (Trans. Ill. Eng. Soc., *18*, p. 861, November, 1923. Abstract).

Apparatus for the determination of color in terms of dominant wave length, purity, and brightness. Jour. Opt. Soc. Am. and Rev. Sci. Inst., *8*, pp. 28 and 173, January, 1924.

A comparison of experimental values of dominant wave length and purity with their values computed from the spectral distribution of the stimulus* (with K. S. Gibson and A. E. O. Munsell). Jour. Opt. Soc. Am. and Rev. Sci. Inst., *8*, p. 28, January, 1924.

Some tests of the precision and reliability of measurements of spectral transmission by the Koenig-Martens Spectrophotometer (with H. J. McNicholas and M. Katherine Frehafer). Jour. Opt. Soc. Am. and Rev. Sci. Inst., *8*, pp. 30 and 201, January, 1924.

The computation of colorimetric purity (with L. B. Tuckerman, Herbert E. Ives and F. K. Harris). Jour. Opt. Soc. Am. and Rev. Sci. Inst., *9*, p. 503, November, 1924.

The specification of color in terms of dominant wave length, purity and brightness* (with K. S. Gibson and A. E. O. Munsell). Jour. Opt. Soc. Am. and Rev. Sci. Inst., *10*, p. 291, March, 1925.

Measurements of illumination and color temperature at Washington during the solar eclipse, January 24, 1925* (with K. S. Gibson and F. K. Harris). Phys. Rev., (2), *25*, p. 901, June, 1925.

Determination of the time of a solar eclipse from measurements of relative illumination* (with K. S. Gibson and F. K. Harris). Phys. Rev., (2), 25, p. 902, June, 1925.

Gray skies and white snow.* Jour. Wash. Acad. Sci., *15*, p. 306, July 19, 1925; Jour. Opt. Soc. Am. and Rev. Sci. Inst., *11*, p. 133, August, 1925.

Standard artificial sunlight for colorimetric purposes.* Jour. Opt. Soc. Am. and Rev. Sci. Inst., *12*, p. 479, May, 1926.

The computation of colorimetric purity, II. Jour. Opt. Soc. Am. and Rev. Sci. Inst., *13*, pp. 123–132, August, 1926.

An experiment bearing on the adoption of a standard neutral stimulus in colorimetry; The choice as between "sun" and "equal energy."* Jour. Opt. Soc. Am. and Rev. Sci. Inst., *13*, p. 306, September, 1926.

The minimum perceptible colorimetric purity as a function of dominant wave length with sunlight as neutral standard* (with F. G. Brickwedde). Jour. Opt. Soc. Am. and Rev. Sci. Inst., *13*, pp. 306–307, September, 1926.

Blue sky and white snow.* Jour. Opt. Soc. Am. and Rev. Sci. Inst., *13*, p. 308, September, 1926.

Apparatus for the determination of the visibility of energy and the fundamental scales of visual psychophysics* (with K. S. Gibson). Jour. Opt. Soc. Am. and Rev. Sci. Inst., *14*, p. 136, February, 1927.

Sensibility to wave-length difference and the precision of measurement of dominant wave length for yellow colors of high saturation* (with Deane B. Judd). Jour. Opt. Soc. Am. and Rev. Sci. Inst., *14*, p. 137, February, 1927.

An experiment on color discrimination under commonplace conditions.* Jour. Opt. Soc. Am. and Rev. Sci. Inst., *14*, p. 138, February, 1927.

Correction of a prevalent error in regard to the data on photometric sensibility as a function of wave length at low brightness. Jour. Opt. Soc. Am. and Rev. Sci. Inst., *15*, p. 82, August, 1927.

Note on the relative comfort in reading by artificial daylight and unmodified gas-filled tungsten lamps. Jour. Opt. Soc. Am. and Rev. Sci. Inst., *15*, p. 131, September, 1927.

Standardizing the red and yellow Lovibond glasses* (with K. S. Gibson). Jour. Opt. Soc. Am. and Rev. Sci. Inst., *16*, p. 116, February, 1928.

Preliminary data on the least perceptible difference in dominant wave length by the method of right and wrong answers.* Jour. Opt. Soc. Am. and Rev. Sci. Inst., *16*, p. 117, February, 1928.

Tests of color sense of A.O.C.S. members and data on sensibility to change in Lovibond red. Oil and Fat Industries, *5*, p. 63, March, 1928.

The selective reflectance of magnesium oxide* (with J. O. Riley). Jour. Opt. Soc. Am., *20*, pp. 156–7, April, 1930.

Note on the yellowness of commercial magnesium carbonate and the alleged yellowness of magnesium oxide.* Jour. Opt. Soc. Am., *20*, pp. 157–9, April, 1930.

Note on the relative sensitiveness of direct color comparison and spectrophotometric measurements in detecting slight differences in the spectral distribution of light.* Jour. Opt. Soc. Am., *20*, p. 159, April, 1930.

LEONARD THOMPSON TROLAND
1889–1932

LEONARD THOMPSON TROLAND

The news of the accidental death of Dr. Leonard Thompson Troland in California, May 27, 1932, in the prime of life and at the height of his brilliant career, came as a shock not only to his intimate friends and associates but to the scientific world at large where he shone as a star of the first magnitude. Born in Norwich, Conn., April 26, 1889, he graduated at the Massachusetts Institute of Technology with the degree of S.B. in 1912. Thereafter he studied psychology under Hugo Muensterberg in his laboratory at Harvard (A.M., 1914; Ph.D., 1915). As Sheldon fellow from Harvard he spent a year or two (1915–16) at the Nela Research Laboratory of the General Electric Company in Cleveland where he pursued optical investigations closely connected with the science of light and vision (flicker and heterochromatic photometry, after-images, Purkinje phenomenon). Between 1913 and 1916 he had published already not less than fifteen papers in various journals ranging over the most abstruse and fundamental questions of physiological and psychological optics. Returning to Harvard, he served as instructor in psychology from 1916 to 1922 and thereafter for the rest of his life as assistant professor and lecturer in psychology. At the same time during the past ten years he has been closely associated with various scientific industries, especially with the development of colored motion pictures; and in 1925 he became research director of the Technicolor Motion Picture Corporation in which he was the guiding genius and inventor of some of their most successful scientific processes.

Troland was a member of many learned societies and took an active and leading part in their proceedings. In 1922–23 he was a distinguished president of the Optical Society of America. Besides numerous important contributions to the journals of these societies, he was also the author of numerous books, namely: *The nature of matter and electricity* in collaboration with Dr. Comstock (Van Nostrand, 1917); *The present status of visual science* (Bulletin Nat. Res. Council, 1922); *The mystery of mind* (Van Nostrand, 1925); *The fundamentals of human motivation* (Van Nostrand, 1928); and last of all a *magnum opus* in four volumes on the *Foundations of experimental psychology* (Clark University Press) of which the first volume on "Visual phenomena" was published in 1929 and the last is now going through the press.

A prodigious and indefatigable worker who like Francis Bacon took all knowledge for his realm, being almost equally at home in chemistry, physics, biology and psychology, Troland suffered a nervous break-

down some months ago and had to take a holiday. He was at Mount Wilson. Standing on the edge of a rocky chasm, Troland posed for a picture which was being taken by a friend, when he lost his balance and fell to his death; only about a month after he had reached the age of 42 years.

Incomplete and utterly inadequate as this brief record necessarily is, it serves perhaps to give some idea of the exuberance of Troland's extraordinary mental powers and the wide range of his activities. He was a born investigator endowed with both capacity and genius, one whom the gods loved and who, alas! died young, as the saying is. From the first, no waywardness of mind, no infirmity of purpose, no perversity of any kind turned him aside from the way of success and from the scientific career that was marked out for him. He went steadily to his goal, acquiring a position in the front rank of the *savants* of his time before he was thirty years of age. The rewards of science are usually not golden, but they are very real and substantial. Troland reaped them easily, and more besides; for he must have gained some of this world's goods to have made provision in his will (as Dr. Roback tells us in *Science*, July 8, 1932) for a fund to be used for investigating that most enigmatic of all puzzles, the "relationship of consciousness and the physical world."

I was somewhat closely associated with Troland for three or four years from about 1921 to 1925. We served together on a committee of the National Research Council on physiological optics in 1921. We were both active officers in the Optical Society of America. I was glad to consult him about the English edition of Helmholtz's *Handbuch der physiologischen Optik*. No man ever impressed me more forcefully; there was no one whose scientific opinion on a question carried more weight or was better informed. Speaking of Troland's influence on others, Dr. Roback hits the nail on the head when he says in his article in *Science* (to which reference has been made already):

"His was an extraordinary combination of the theoretical and the practical. The theoretical scientists respected him because of his technological achievements, while technologists admired him for his vast fund of theoretical knowledge."

Science and poetry are twin sisters, for in those branches of science that are most abstract, most formal and most remote from the grasp of the ordinary sensible imagination, a higher power of imagination akin to that of the poet, nay indeed far exceeding it, must be summoned to enable us to leap across the unseen and link the glimpses of obdurate

facts into a coherent and harmonious whole. Troland was not a poet in the accepted sense of the word, and indeed I doubt whether he had much taste for mere literature of any kind; but he had that fiery and constructive energy that projects itself into the tangible world and at the same time assimilates the surrounding world to itself. His perceptions were quick and accurate, his sympathies were manifold, not cramped and narrow, as is the misfortune and weakness of most specialists and scientific investigators; and so he could see almost instantly another's point of view and reconcile it to his own. This faculty made him a delightful scientific companion with whom ideas could be freely interchanged and who always shed light on a subject.

The Optical Society of America has sustained irreparable losses in the untimely deaths, only a few weeks apart, of two of its brightest ornaments and most highly honored members, past-Presidents Leonard Thompson Troland and Irwin G. Priest.

J.P.C.S.

COLUMBIA UNIVERSITY,
NEW YORK, N. Y.,
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